THE IMPACTS OF COMMERCIAL MAINTENANCE TECHNOLOGY ON ARMY MATERIEL MAINTENANCE PRACTICES

SSCF Independent Research Project
(DAU Research Report SSCF-MW 08-3)

Mitchell Kozera

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CHAPTER 1
INTRODUCTION

Vehicle readiness and availability are critical to supporting our logistics mission, both in peacetime and while we fight the Global War on Terrorism. By and large, vehicle diagnostics are performed on military vehicles with off-board test tools that don't readily address the vehicle operator's up-to-the-minute need for information on impending problems or failures. The reason is that the absence of on-platform technology impedes the flow of up-to-the-minute information about vehicle condition, which restricts the operator from performing the necessary field-level maintenance required to satisfy his vehicle's readiness needs.

While heavy and depot-level maintenance, troubleshooting, and diagnostics can be, at least in part, addressed with the use of off-board test sets, operator maintenance requires the insertion of some level of sensing and wireless communications technologies into the vehicle platforms. This helps to accomplish the dissemination of diagnostics data to the mechanic to allow him or her to perform the desired maintenance functions. While many of these solutions are being explored and even used in the Service branches, many more may be available for transition from technology developed by globally influential companies such as International Truck and Engine Corporation (also referred to in this paper as International Truck), Daimler Corporation, and Ford Motor Company.

The rationale for discussion is that maintenance technologies developed for the commercial market with process efficiency in mind may have impact on operator-level maintenance practices and procedures in both maintenance hours and platform downtime. Specifically, technologies like the Driver Tech DT-3000A diagnostic computer (a commercially developed technology intended to automate diagnostics processes) or International® *AWARE*™ (the diagnostics management product of International Truck and Engine Corporation) may prove to reduce vehicle diagnosis time. These technologies potentially allow for repair activities to commence as soon as the vehicle reaches the depot, rather than having to go through a diagnostics check with off-board test equipment.

This study aims to investigate Army maintenance practices and the impacts on maintenance turnaround time of using maintenance technologies developed to service the global marketplace. The main method for data collection on Army systems is utilization of the extensive reports generated from the Army's Integrated Logistics Analysis Program (ILAP), the primary source of maintenance information in the Army. Maintenance turnaround time was analyzed for the Army's M915 series line haul truck in Iraq and at Fort Hood, TX, one of the Army's busiest installations for deploying vehicles to active status. The M915 was selected based on its close kinship to platforms in commercial long-haul trucking.

Discussions were initiated with maintenance representatives from International Truck and Engine Corporation to gain information on maintenance turnaround time on International Truck's truck fleet. The results of these discussions indicate that the impacts of employing maintenance technologies developed in the commercial market are very positive. International Truck is working towards developing solutions to automate the diagnostics data-gathering processes as well as proactive analysis of diagnostics data prior to the vehicle's reaching the maintenance bay.

While International Truck's intent is to move development of their International *AWARE*™ product in the direction of automating diagnostic and parts-requisition processes, it was discovered during research that they are still in the early stages of development and anticipate seeing versions of a workable system as early as 2009.

Background of the Report

Army maintenance practices have roots dating back to World War II, when vehicle systems were far less complex. In the decades since, we have seen significant technological advancement in military systems. Because of these changes, Army foundational maintenance practices and procedures must be updated (Butcher, 2000). The overall reduction in Army maintenance personnel (Stevenson, 2002) suggests that commercial technologies developed for use in the global marketplace may have an impact on alleviating the logistics burden-associated excessive maintenance turnaround time.

Research Question

What are the impacts of utilizing commercially developed maintenance sensing and wireless communications technologies on Army ground vehicle maintenance, specifically on the time that elapses from when a maintenance work order comes in to the time it takes to return that equipment to service, defined as maintenance turnaround time?

Statement of Purpose

The focus of this initiative is to study current commercial maintenance practices and technologies developed for use in the global marketplace. This study will assist in identifying the potential impacts of using those technologies and approaches on Army maintenance practices, in order to understand whether their use can be applied to shorten Army maintenance turnaround time.

Research Proposition

This study will determine the impacts on maintenance turnaround time of inserting commercially developed maintenance technologies into Army ground systems. This is a directional proposition stating what the anticipated effects of integrated sensing and wireless communications technologies will have on Army maintenance processes and practices. Plans include developing an argument on what the incorporation of integrated sensing and wireless communications technologies into the Army vehicle fleet means, from a maintenance management perspective, on maintenance turnaround time. This includes extrapolating the effects of utilizing technologies developed for commercial automotive and trucking applications in the same space.

The population from which the data are collected is Army maintenance work records for the M915 series tactical vehicle system programs, as well as maintenance turnaround time for commercial trucking vendors, so that an analysis of potential impact can be performed.

Definitions

The many Army-centric and less familiar terms related to maintenance have been defined in depth in the body of this report. Included are a few additional important terms and their definitions.

***Data bus*—**This is the on-vehicle local network that interconnects electronically controlled subsystems such as the engine and transmission to optimize performance and enable diagnostics data collection. Also, this network allows for the connection and/or integration of maintenance technology to accomplish repair tasks. Examples of data bus technology include the Society of Automotive Engineers J1708 and J1939 technology (dos Santos & Onusic, 2002). J1939 is the current data bus standard that emerged in the middle 1990s for commercial trucking (Keller, 1997). J1708 was its predecessor and originated in the early 1980s (Furth, 1996). J1850 and Control Area Network, which will be covered later in this literature review, are two additional data bus standards that first appeared in the early and middle 1980s, respectively (Miller, Thomas, & Waldeck, 2004) (Table 1).

Data Bus Standard	Era Introduced
J1939	Mid 1990s
J1708	Early 1980s
J1850	Early 1980s
Control Area Network	Mid 1980s

Table 1. Data Bus Standards (Furth, 1996; Keller, 1997; and Miller, et. al., 2004)

***Depot-Level Maintenance*—**Depot- level maintenance is the repair work or scheduled maintenance conducted in a depot maintenance bay, as opposed to short-task repair work that can be conducted in the field (e.g., flat tire fix). This work typically involves more detailed tasks that require the use of technical manuals and/or computerized test equipment (Army Materiel Maintenance Policy, 2007).

***Diagnostics Data*—**These are the fault and symptom data that are generated by operational events and conditions on an electronic control module on a vehicle system. These electronic control modules are typically integrated with an engine, transmission, or other electronic subsystem in a vehicle. As well as generating the diagnostic data, they also save the data so it can be retrieved and analyzed at a later time (Butcher, 2000).

***Interactive Electronic Technical Manual*—**Interactive Electronic Technical Manuals, or IETMs, are diagnostics test computer-resident electronic or digitized versions of paper repair manuals. IETMs include, as features, electronic hyper-links that allow the maintenance technician to navigate directly to the page providing step-by-step instructions to implement the fix (Butcher, 2000).

***Maintenance Technology*—**Maintenance technology, for the purpose of this study, can be defined as sensors, computers, and communications devices that capture, rationalize, store, and distribute diagnostics data. These devices can be used as a set of integrated products, as is being done in the commercial automotive industry. They can also be used as a set of computerized test tools employed in a maintenance bay (Butcher, 2000).

Maintenance Turnaround Time**—**This is defined as the period of time that elapses between maintenance organization's accepting a work order and the vehicle's release back to service. It includes the time to acquire the parts needed to complete the fix and the actual repair activity time (Army Materiel Maintenance Policy, 2007).

Observation, Equipment Service, Fault Repair, and Single-Standard Repair**—**The Army relies on four core maintenance processes for vehicle system management over the course of its useful life: visual inspection, scheduled maintenance, fault repair, and single-standard repair. Following is a description of each.

> **Observation** is a process conducted with a paper check list to verify critical baseline functions on a vehicle prior to its deployment on an operational mission. This process ensures that the vehicle can execute its mission and return safely, barring any battle-inflicted damage.
>
> **Scheduled maintenance** is a list of regular actions that are required by the original equipment manufacturer to maintain a vehicle's state of readiness under normal operating conditions.
>
> **Fault repair** is maintenance required to remedy an unexpected problem in the system and is usually diagnosed with the help of off-board diagnostics computers.
>
> **Single-standard repair** is the process that requires all maintenance be performed using the same toolsets and attention to quality to ensure consistent and predictable service life (Army Materiel Maintenance Policy, 2007).

Recapitalization**—**Recapitalization is defined as returning the vehicle system to its original operational capability, using repair or rebuild processes (Army Materiel Maintenance Policy, 2007).

Vehicle Readiness**—**Vehicle readiness is quantified as the level of operational availability and mission reliability of a vehicle system. It can be described as a percentage of the fleet or in sheer numbers of available vehicle systems to conduct a mission (Butcher, 2000).

CHAPTER 2
LITERATURE REVIEW

Introduction

This chapter will present a review of the literature that addresses Army maintenance procedures, regulations, and practices, as well as a cross section of maintenance as it is handled in the commercial passenger car and light truck industry, and commercial trucking. For the purpose of this report, the focus will be limited to wheeled ground vehicles.

The opening section of this literature review will describe current Army maintenance policies and practices. This description will go into detail on how the Army prioritizes maintenance work, documents the activity, and measures the success of the activity (Army Materiel Maintenance Policy, 2007).

Army maintenance is an important subfunction of logistics management. The literature review will discuss and describe how maintenance factors into the Army's logistics burden and how the Army's Logistics Modernization Program integrates parts requisition processes with maintenance work order data to facilitate repair part acquisition (Carroll & Coker, 2007).

The literature review will also define global economies of scale as they pertain to commercial maintenance technologies, and then review the application of these commercial technologies to improve Army maintenance processes. Additionally, a basic historical perspective of Army maintenance practices will be discussed in order to establish a baseline for technology insertion of commercially based products into the Army maintenance process.

Examples of recent product improvement initiatives to Army maintenance will be discussed to lend credence to the prospect of modernization of Army maintenance practices. More detailed discussion will also be provided on Army supply chain management to create a baseline for incorporating commercial standards to parts inventory and information management (Supply Chain Management, 2006).

The following sections of the literature review will address commercial maintenance practices and technology approaches, taking time to explain solutions that have been in use in the commercial automotive industry. The discussion will touch upon the impacts of traditional American companies like Chrysler and Ford developing and selling their products in the European market and the impacts on standardization with their American counterparts (Miller, Thomas, & Waldeck, 2004).

The discussion will shift to activities in the commercial trucking industry and the use of worldwide standards, like those sanctioned by the Society of Automotive Engineers and the American Trucking Association. Areas of focus will be standard recommended practices for maintenance in use globally.

The literature review will finish with a synopsis of the development of the International *AWARE*™ diagnostics and communications product of International Truck and Engine Corporation and its potential leverage into Army maintenance processes.

Description/Explanation of Current Army Vehicle Maintenance Policies

The purpose of Army maintenance is to preserve vehicle readiness, maintain combat and tactical effectiveness, and preserve the capital investment of our systems and their capability in supporting training and mission accomplishment. The Army maintenance policy is based on the principle that the useful service life of an Army system is realized if operated within its intended purpose and maintained in accordance with its designed specifications.

In the event that a vehicle system or component reaches its useful life, the Army uses procurement, recapitalization, or overhaul to replace the element or reset its usefulness. As mentioned earlier, the Army uses four key processes to evaluate and manage the utility of its equipment during the course of its useful life: observation, equipment service, fault repair, and single-standard repair (Army Materiel Maintenance Policy, 2007).

Observation for performance quality is the foundation of the Army maintenance paradigm and is the basis for preventative maintenance, checks, and services (PMCS). PMCS is one of the first descriptive requirements of all Army equipment technical manuals in regard to pre-operation inspection and after operation checks. With the digitization of Army technical manuals—also known as the interactive electronic technical manual (IETM)—which is becoming commonplace for all systems, the Army is in the process of automating the recording and transference of PMCS data. PCMS can be collected via embedded sensor, enabling a methodology known as condition-based maintenance.

Equipment services are specific maintenance actions that are performed as required or as routine maintenance that includes adjustments, checks, and changes to the equipment, including maintenance such as lubrication and tire changes. Such maintenance actions are over and above the regular PMCS functions and are in accordance with requirements as defined by original equipment specifications.

Fault repair is the process of returning the equipment to its original designed specification and includes the use of off-platform test equipment to help diagnose problems down to the component level.

Single-standard repair is intended to ensure use of a consistent technical standard to maintain all end items, secondary items, and components. This allows for consistency, high quality, and more predictable service life. The standard for Army maintenance is to maintain the operational capability of the systems as instructed and described in the vehicle operator technical manuals (Army Materiel Maintenance Policy, 2007).

Priority Designators

Army maintenance tasks and operations are conducted based on priority. The designation assigned each task is predicated on the importance and relevance of the mission of the organization requesting the maintenance. In the Army's maintenance management system, this importance is expressed as urgency of need, or the urgency need designator (UND) (Figure 1). This designator or ranking connects directly to an established high limit of acceptable maintenance turnaround time based on maintenance action's mission need (Army Materiel Maintenance Policy, 2007). Following is a more in-depth explanation of Figure 1, organized by maintenance priority designator.

Table 3–1
Priority designator (relating force/activity designator to urgency of need)

Force activity designators	Urgency of need designators		
	A	B	C
I	01	04	11
II	02	05	12
III	03	06	13
IV	07	09	14
V	08	10	15

Table 3–2
Maintenance priority designator and TAT standards

Maintenance priority designator	TAT standard
01–03	5 days
04–08	8 days
09–15	30 days[1]

Notes:
[1] Customer organizations may specify a required delivery date that is longer than 30 days when mission schedules permit.

Force Activity Designators
I: In Combat
II: Positioned For Combat
III: Positioned to Deploy
IV: Other Active and Reserve
V: All Other

Urgency of Need Indicators
A: Unable to Perform Mission
B: Impaired Operational Capability
C: Routine Issue

Figure 1. Priority Designators and Urgency Need Indicators (Army Materiel Maintenance Policy, 2007)

MPD 01–03: If a vehicle is unable to perform its mission *while in combat, being prepared for combat, or being prepared for deployment*, it is MPD 01-03. The metric stipulates that repairs of this prioritization must be completed within 5 days.

MPD 04–08: Vehicles *not in a combat environment that are also not mission capable are MPD 7-8*. The metric stipulates that these vehicles must have maintenance completed within 8 days.

Vehicles *in a combat environment that have some capability but are impaired* are prioritized as MPD 4–6. These types of repairs must also be completed within 8 days.

MPD 09–15: This priority designator is in place to cover every other potential circumstance. Included are vehicles in *active or reserve roles other than combat, with some functionality but impaired capability (MPD 9, 10)*. These systems are lower priority than those being positioned for combat or those already on combat detail. The metric stipulates that these vehicles should, if possible, have maintenance completed within 30 days. *All other routine maintenance, regardless of circumstance or environment (MPD 11–15)*, falls within this category and should also be completed within 30 days. MPD 09–15 is the lowest priority classification and can even exceed 30 days, if customer organizations specify a satisfactory date outside of the 30-day metric.

Record Keeping

Accuracy and completeness of record keeping are critical to the success of any fleet maintenance program. Army commanders use data from a number of sources to configure and validate the maintenance manpower resources and force structure. Such resources include the Army Logistics Support Activity (LOGSA) logistics integrated database (LIDB), Unit Level Logistics System (ULLS), Standard Army Maintenance System (SAMS), and the Integrated Logistics Analysis Program (ILAP). All utilities perform a different function but are, in theory, aligned to function as an integrated suite (Army Materiel Maintenance Policy, 2007).

Maintenance Management Metrics

The primary maintenance metrics used in the Army are total logistics response time and turnaround time. Total logistics response time—maintenance (TLRT-M)—is defined by the period of time that elapses between the time an item of equipment or component becomes unserviceable and the time that the item or component is returned to a serviceable status after receiving the requested repair or services.

Turnaround time (TAT) is defined as the period of time that elapses between when a maintenance organization accepts a unit work order, accomplishes the work, and closes out the order. It is the goal of Army organizations performing maintenance to minimize TAT and provide assistance so that organizational TRLT-M is as low as possible (Army Materiel Maintenance Policy, 2007). It is the focus of this study to determine potential impacts to TAT.

The Army Maintenance System

The Army Maintenance System, also known as two-level maintenance, consists of maintenance in two categories: field level and sustainment level.

Field maintenance refers to maintenance performed primarily by inspecting or observing the performance of the system. This type of maintenance is often performed by the operator, with the goal being to diagnose the problem, fix it, and return the vehicle to service as soon as possible. Sustainment maintenance is characterized by more in-depth repairs performed in a maintenance bay or job shop setting, often with the assistance of off-board test, maintenance, and diagnostic equipment. Ordinarily, these repairs are completed by someone other than the vehicle operator, since the operator will have transported the vehicle to the maintenance facility and left it for the repair work. It is during sustainment maintenance that the bulk of the diagnostic fault code data are collected, using off-board computers. The data are then analyzed using diagnostic test algorithms, also hosted on the off-board computer. These computers also contain Army interactive electronic technical manuals (Army Maintenance Management System Users Manual, 2005), which, when fed the diagnostic fault code data, have the ability to autonomously navigate to the proper section with directions to apply the fix.

Description of Army Logistics Practices Related to Maintenance

The Army's main logistics management initiative, Logistics Modernization Program (LMP), coordinates the major Army logistics functions, including depot level maintenance planning and execution. LMP uses a software-based enterprise business system to establish shared common logistics data from fielded vehicle systems across suppliers and contractors. The contractors provide parts and services to support national maintenance functions. LMP replaces a collection of antiquated data storage and analysis functions and succeeds in coordinating information systems into an enterprise to support Army logistics.

LMP has been in place since July 2003. An excerpt from the Army Logistician online journal describes how far LMP reaches in the Army logistics enterprise:

> Today, the LMP manages $4.5 billion worth of inventory, processes transactions with 50,000 vendors, and integrates with more than 80 DoD systems. The LMP is deployed to 4,000 users at the Army Communications-Electronics Life Cycle Management Command (C–E LCMC); Tobyhanna Army Depot, Pennsylvania; the Defense Finance and Accounting Service; and a dozen other Army and DoD locations. When fully deployed, LMP will support more than 17,000 logistics professionals (Carroll & Coker, 2007). LMP is a critical element of the larger Single Army Logistics Enterprise (SALE).

SALE incorporates connectivity to requisition management software functions that allow global maintenance work order data collection. This work order function uses products such as Standard Army Maintenance System software (SAMS) to coordinate the repair action with part supply support using Unit Level Logistics System (ULLS) (Figure 2).

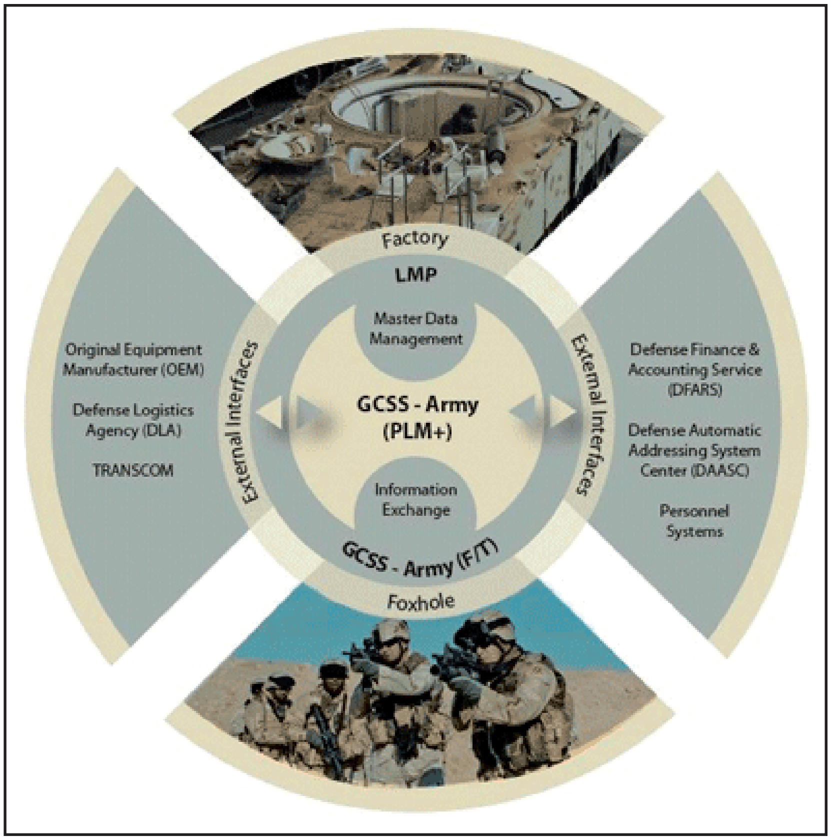

Figure 2: Single Army Logistics Enterprise (Carroll & Coker, 2007)

LMP provides key support for national and global maintenance program oversight. It provides Army item managers, program managers, and maintenance workers the ability to collaborate to improve maintenance repair times, supply parts on demand, and manage inventories (Carroll & Coker, 2007).

Other areas of logistics support related to Army maintenance include the maintenance assistant and instruction teams (MAIT) program and the *Preventive Maintenance Monthly* publication. The MAIT program assists in establishing readiness goals and methods to achieve those goals in increased operational tempo scenarios such as the high mobilization requirements of war.

Preventive Maintenance Monthly is a publication developed and provided by the Department of Army that offers directions to help enhance unit readiness by identifying and optimizing maintenance and supply procedures in a quick-to-read tabloid (Army Logistics Readiness and Sustainability, 2004).

Definition of Global Economies of Scale in Relation to Maintenance Technology

Global economies of scale as they apply to maintenance are defined as the subset of the world market that buys and consumes commercial diagnostics technologies built to worldwide technology standards, such as SAE J1939 and Control Area Network. To the extent practicable, this study will explore the use of technologies not traditionally used in the maintenance process, such as wireless communications and commercial off-the shelf sensor and computing technology, to determine their potential impact on Army maintenance turnaround time.

Army Maintenance—A Historical Perspective

Historically, Army maintenance can be compartmentalized into two broad categories: four-level maintenance and two-level maintenance.

The four-level maintenance paradigm was created and instituted just prior to World War II and served the Army for over 50 years, until Army transformation initiatives led to a restructuring of the maintenance concept to two-level in the early 2000s (Stevenson, 2002). Four-level maintenance consisted of the following elements:

- Unit/organizational level: All maintenance is repair and return to the user.
- Direct support (DS): Maintenance is mostly repair and return to user; some is repair and return to supply.
- General support (GS): Maintenance is mostly repair and return to supply; some is repair and return to user.
- Depot: Maintenance is repair and return to supply.

The paradigm is characterized by the simplest task being performed at the lowest echelon or level. In this case, that is unit or organizational level. That means that for the four-level maintainer, no operators were responsible for performing any maintenance. When an issue arose in the field, the vehicle was transported or driven back to the organizational repair facility and fixed. It was then returned to service, directly to the user.

Direct support involved more in-depth repairs, but the goal remained the same: to return a fully mission-capable vehicle to the user in the shortest time possible or, on rare occasions, return it to supply to be reassigned. General support involved yet more intrusive repairs that may even have required that the vehicle be transported to a different nearby facility to receive the repair before being returned to service.

Depot-level maintenance involved transporting the affected vehicle system to a remote depot facility, sometimes back to the continental United States from abroad, to receive extensive repairs and overhaul. This level of maintenance invariably led to the system's being returned back to the supply chain (Stevenson, 2002).

The four-level maintenance practice contributed a large logistics burden that relied on extensive evacuation procedures and built-in maintenance overhead requirements at each level during both wartime and peacetime. With the reduction in maintenance personnel in the current Army, the need for reduction in maintenance burden was readily evident.

Two-level maintenance represents a reduction, by half, in the number of levels in the Army maintenance paradigm. Two-level maintenance is broken up into two groups: field level and sustainment level. The field maintainer is often the same individual who regularly operates the vehicle. The maintainer also performs visual inspections, utilizes specialized tools to diagnose faults, and replaces components to facilitate quick return to service. Field-level maintenance replaces the organizational and direct maintenance function by providing the maintainer the toolsets, authority, and capability to perform field maintenance functions. The new organizational approach to field maintenance allows for the creation of a mobile maintenance support team for fielded units in a forward area of responsibility. This added functionality, with less logistics overhead, enables on-the-spot upkeep of mission-capable vehicle systems.

Sustainment-level maintenance replaces general and depot-level functions. Sustainment-level maintainers perform more intrusive and extensive repairs and overhauls that necessitate the vehicle's being out of service for longer periods. Ultimately, much like the depot function of four-level maintenance, the vehicle is cycled back into the supply system and dedicated back to mission needs at a national level.

The two-level maintenance concept has been successful in the Stryker Brigade Combat Team deployments, with the most notable benefits being consolidated institutional maintenance knowledge and merged maintenance training to accommodate the reduced number of Army maintainers and smaller logistics footprint (Stand To!, 2007).

Off-board Test Tools

Currently in the Army, the primary method for diagnosing faults in vehicle systems is by use of off-board test computers with Army-specific software tools. The systems used on Army automotive-based platforms are the Soldier's Portable On-system Repair Tool (SPORT) and the Maintenance Support Device (MSD).

Soldier's Portable On-system Repair Tool

SPORT is the first generation Microsoft® Windows®-based test computer used by the Army to coordinate a physical connection between the vehicle diagnostics network and the vehicle interactive electronic technical manual (IETM). In its earliest incarnations, in the late 1990s, SPORT had the capability to poll the vehicle for basic parameters such as system voltage, engine temperature, and fluid pressures. Subsequent iterations in the early 2000s included interfaces to the FMTV J1939 and J1708 data busses, and with improved IETM products, the ability to collect data from the FMTV engine, transmission, anti-lock braking system, and the vehicle central tire inflation controller. Projections in 2001 included $341 million in consumable savings and $980 million avoidance in maintenance costs (Lees, 2001). The version of SPORT spawned the upgrade and renaming of the technology to Maintenance Support Device (MSD).

Maintenance Support Device

The MSD is currently the de-facto off-board test computer for Army trucks; it incorporates the same basic diagnostics data bus interfaces as SPORT and adds improvements in data storage space to accommodate larger diagnostics software applications and diagnostics data storage. MSD also incorporates modern USB and PCMCIA interfaces for dynamic download of software changes to the diagnostics tools (“Maintenance Support Device Specifications,” 2007).

The SPORT and MSD represent a positive shift in computer-based diagnostics for Army vehicle systems. However, at price points in the tens of thousands per unit, this device is cost-prohibitive as an integrated solution.

Examples of Army Diagnostics—Army Diagnostics Improvement Program and Common Logistics Operating Environment

This section will describe the Army Diagnostics Improvement Program (ADIP) and the Army’s Common Logistics Operating Environment (CLOE) and their respective connections to Army maintenance.

Army Diagnostics Improvement Program

The Army Diagnostics Improvement Program (ADIP) is an example of the Army’s intent to modify maintenance processes to incorporate the use of advanced computing technology and remote data storage (Butcher, 2000). ADIP started the process of developing a global enterprise perspective of the predictive maintenance process and ultimately prognostics in Army ground systems.

The ADIP program (Figure 3) ran from 1998 to 2005. The intent was to impact all legacy ground vehicle systems by reducing “no evidence of failure” (NEOF) by 50 percent and reducing life cycle costs by 20 percent. NEOF is a phenomenon that exists when a seemingly faulty component is removed from a vehicle system and tested for diagnostic health independently of the vehicle, and, for whatever reason, no problems are found. This usually results in putting a new component back in its place and taking an operational component out of service. The new components are very costly to produce, and the logistics of storing removed components are a significant burden on vehicle inventory managers.

The key to the ADIP approach was to integrate technology such as data busses and additional sensors with advanced communications and data analysis tools to create infrastructure that can reach from U.S.-based Army logistics management facilities to global areas of responsibility. The linkage would provide anticipatory information to integrated logistics support professionals and supply chain managers, allowing the managers to effectively provide maintenance-related supplies on an as-needed basis (Butcher, 2000).

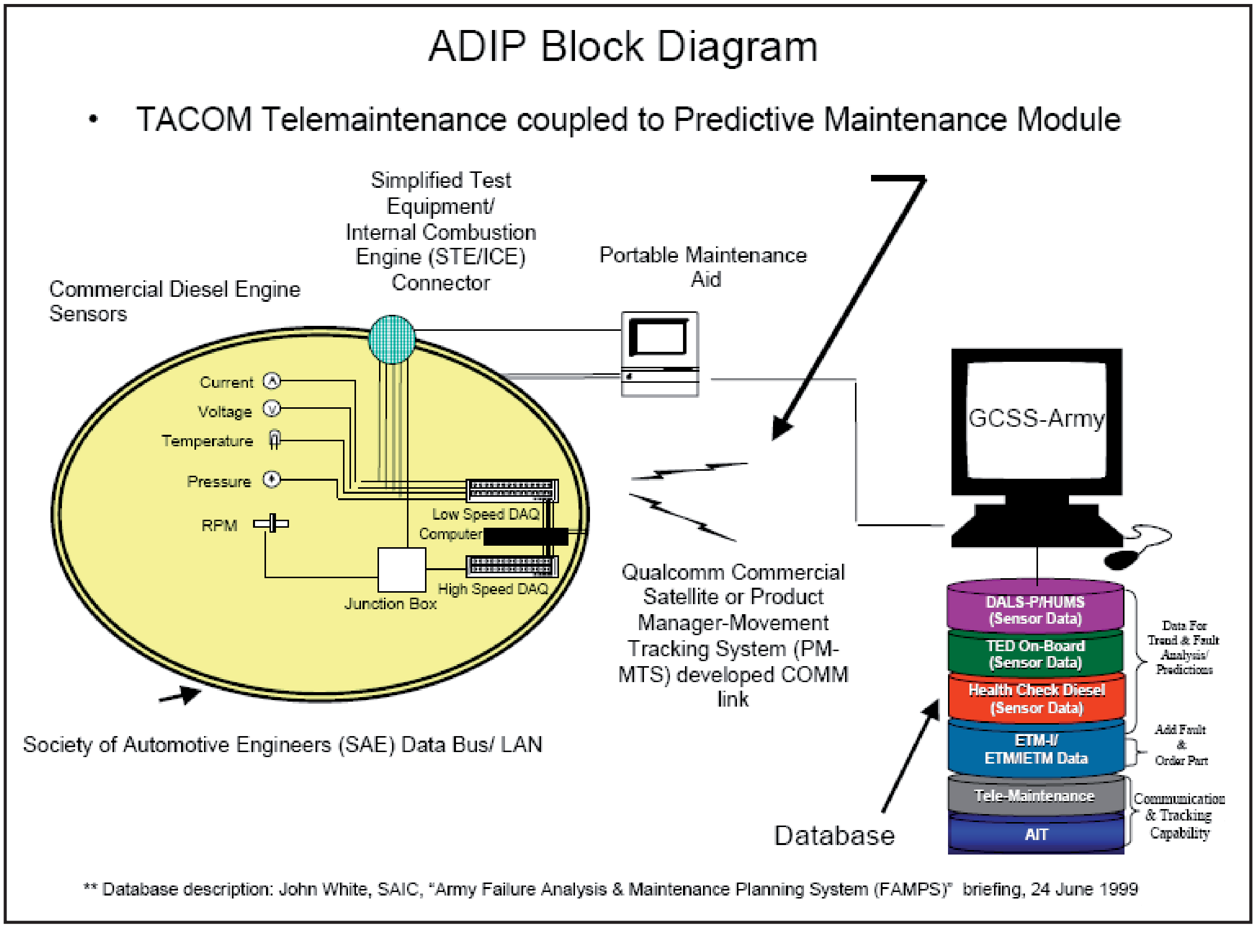

Figure 3: Army Diagnostics Improvement Program (Butcher, 2000)

Common Logistics Operating Environment (CLOE)

The need for a reliable demonstration to prove the concept of ADIP led, in part, to the development of CLOE.

According to the CLOE Web site (no longer in existence but similar information is to be found at <www.army.mil/aps/08/information_papers/transform/Common_Logistics_Operating_Environment.html>):

> The CLOE is a process to achieve the Army's vision for developing a technology-enabled force equipped with self-diagnosing equipment platforms that interact with a network sustainment infrastructure that supports condition-based maintenance. The CLOE strategy allows the Army to transition to a unit-centric focus for specific units of action (UA) and their supporting unit of employment (UE). CLOE sets common data standards, specifications, and protocols necessary to integrate platform, information, and C3 technologies for use in the Objective Force logistics sustainment. CLOE capabilities represent a unique blend of embedded command, control and communications (EC3) interfaces and equipment configurations designed to integrate platform-level equipment and consumable status information with the Army's logistics enterprise environment; therefore it is termed an

> “operating environment” even though it is not in itself an information system. The CLOE operating environment extends to all equipment platforms used in the Objective Force, including ground combat, ground support, aviation, and watercraft (“CLOE Program Mission,” 2003).

The CLOE operational evaluation exercises in 2003-04 used tests, demonstrations, simulations, and user assessments to validate the CLOE design (“Major Agency Projects,” 2007). The exercises also incorporated use of the previously mentioned Driver Tech DT-3000 vehicle computer. The DT-3000 was picked because of its commercial origins, its ability to gather data from Army automotive-based diagnostics architectures, and its military-style ruggedness. The DT-3000 allowed for the local capturing and interpreting via IETM and the communication of diagnostics data to the logistics enterprise using commercial communications standards such as 802.11 a/b/g and the Army’s tactical internet. The DT-3000 sits today as a recognized alternative to outfit Army trucks with embedded diagnostics computing, pending the availability of funding.

Logistics Management of Maintenance Parts Requisitions

Unit Level Logistic System (ULLS) and Standard Army Maintenance System (SAMS) are software-based applications that work hand in hand to coordinate the requisition of maintenance parts to the maintenance work order that describes the need for that part.

The ULLS function is to manage parts supply at company level. As an automated software tool, ULLS tracks the warehouse location of a needed part. ULLS allows for the accounting classifications to requisition the part to the correct unit to conduct the maintenance action. It also has the ability to conduct searches and initiate transactions using an internal cataloging function. ULLS automatically applies ownership of any equipment requisitioned through it to the receiving organization, a reduction in the logistics burden of inventory management over previous methods (Munger, Ritter, Shelton, Camacho, & Cline, 1997).

SAMS is the application that stores and sorts maintenance work orders based on the description of the maintenance action, related fault data, and the parts required to accomplish the fix. SAMS has gone through several generational upgrades. The current version captures the core functionality of ULLS and ties the maintenance action directly to the requisition of the parts needed to complete the desired repair. SAMS is built upon a familiar Windows-based user interface and is designed to function at company level but can be modified to work at higher organizational levels to accommodate combat and combat service-support needs (Cerda, 2007).

Army Supply Chain Management

As part of the Logistics Modernization Program, the Army has gone to great lengths to find parallels in military logistics and commercial logistics. In 1999, then Deputy Under Secretary of Defense for Logistics, The Honorable Roger Kallock, defined his goal for effective supply chain management as requiring three key ingredients: information-driven logistics, a fully integrated system, and customer-focused logistics. These are the same requirements that can be found in commercial industry. One need not look much further that the terrorist attacks of September 11, 2001, to see the critical similarities in logistics support requirements between industry and the military for surge events. Both involve fundamental processes such as the rapid exchange of information, identification of available supply lines, and delivery of critical supplies. Such scenarios call for an integrated plan involving military, governmental, and commercial services (Leiphart, 2001).

The supply chain model being employed as part of LMP incorporates the following:

Standardization of commercial and military logistics metrics and equipment. Establishing standards for measuring success is a necessary step to modernizing supply chain management. This is especially true when considering the idea of utilizing commercial vendors to provide their approaches, which may not be congruent with the ways the Army does business.

Real-time inventory information. Real-time inventory information is important. The ability to integrate this information improves supply on demand and reduces the burden of redundant storage of parts.

Minimal customer wait time. The combination of streamlined procurement, supply, distribution, and lean practices is fundamental to creating an efficient supply chain management system. Technology and refined processes have made it possible to achieve change in this area with a level of investment that is less than ever before (Leiphart, 2001).

As military resources become increasingly scarce, the Army will undoubtedly become more reliant on advances in technology, joint use of public assets such as transportation, and even deeper inventory reduction to mirror that of commercial industry.

Description of Commercial Maintenance Practices

With respect to the Army’s maintenance practices, the most impact can be gained by attempting to leverage maintenance activities as they are performed in the commercial automotive and trucking industries. Primary areas of influence exist in the commercial automotive sector’s on-board diagnostics (OBD) generations I and II and the networked diagnostics architectures that are defined by the Society of Automotive Engineers (SAE) serial data protocols J1939 and J1708.

On-board Diagnostics I and II

OBD I and II have been in use on commercial passenger cars for over a decade and offer maintenance technicians a convenient point of access into a central diagnostics module that has the ability to query, actuate, and control the many submodules and smart sensors on a vehicle platform. All cars and passenger light trucks built after January 1, 1996, are required to be equipped with OBD I or II capability. While the original impetus for developing the OBD protocol was to diagnose problems in emission systems, the technology has grown to include power train and most electronically controlled elements of the vehicle. Because of design constraints, the data created and distributed from this protocol isolate only the faulty subsystem. It is not typically sufficient to diagnose problems at the discrete component level, which is a goal of Army diagnostics (You, Krage, & Jalics, 2005).

In order to supplement the low resolution of information available with OBD solutions, maintenance technicians use a variety of off-board test technologies to capture a higher level of capability. This lowers the burden on the in-vehicle computer processing and allows commercial passenger car technicians to rely on a level of past experience to diagnose faults (Foran & Jackman, 2005).

Typically, J1939 and J1708 serial data architectures have been used in heavy commercial long-haul trucking applications to network the electronically controlled elements of a drive train and power train of a vehicle. Freightliner and International Truck and Engine are examples of manufacturers that use the architecture. The platforms that these companies produce are closely akin to two truck series that the Army fields: the Family of Medium Tactical Vehicles (FMTV) and Heavy Expanded Mobility Tactical Truck (HEMTT).

Much like their commercial counterparts, the FMTV and HEMTT use the J1939 data bus as a means to optimize control between the engine, transmission, and braking systems to gain the best possible performance. Diagnostics connectors are integrated into the network to intercept the data parameters that tell of impending problems between the drive train systems. The J1708 data link is the previous generational standard for diagnostic interface. J1708 uses the same commercial interfaces as J1939 and is used, as well as older, legacy commercial equipment, by the Army to capture all other data elements not networked by the J1939 (Kozera, 2002).

Commercial industry and the Federal Motor Carrier Safety Administration consider the J1939 serial data architecture to enable critical functionality in networking and optimizing performance of truck, bus, off-road, construction, and marine vehicle applications. It is considered that vehicle readiness and optimal performance are key aspects of vehicle safety:

> The J1939 communication standard is a control and information data bus that supports critical safety-related systems and subsystems on heavy-duty tractors, trucks, converter dollies, and trailers. Safety-critical systems currently in production that utilize (or have the potential to utilize) the J1939 network include engines, transmissions, drive slip control (subset of antilock brake systems), collision avoidance, and lane guidance systems. Since the J1939 network represents an advanced high-speed network, the number of subsystems utilizing this network, both safety-critical (as related to fundamental vehicle systems and controls in the context of this study) and non-critical systems, will likely continue to increase on future commercial vehicles (Freund, 2007).

Control Area Network

This literature review would not be complete without mention of the Control Area Network (CAN). CAN is the communication layer protocol that defines the data formats that travel from node to node across the hardware network. It allows for the networking of discrete electronic modules so that they may interconnect to optimize performance, as described earlier in this section. The beginning of CAN's development predates the development of the J1939 by only a short amount of time. The actual data transport protocol CAN defines was being standardized just before the J1939 hardware layer went into development. SAE released its first standard incorporating both protocols in 1998 (Brady, Nicosia, Long, & Gefke, 2007).

In addition to its ability to exchange data between network nodes to facilitate seamless control, the significance of the CAN protocol is that it has been used in Europe since the late 1990s. As its use in the commercial automotive sector becomes more global in impact, its complete proliferation into American commercial and military diagnostics should become a near-term reality.

Examples of Commercial Approaches

In the commercial automotive industry, some maintenance intervals are preprogrammed, computed timeframes based on the number of start cycles and the number of times a vehicle reaches nominal operating temperature.

In many cases, these program parameters are based on the vehicle's anticipated operational environment. If that environment should change and the parameter stays the same, the maintenance interval becomes invalid. An example of this is oil change interval. Most passenger cars are programmed to alert the user of a required oil change at 3,000 miles. The condition of the fluid does not factor into the "decision" by the vehicle to alert the operator. Regardless of whether or not the vehicle has been driven in conditions that warrant the oil change, the vehicle continues to instruct the operator to change the oil. This action results in many needless oil changes, large amounts of waste oil that otherwise has useful service life, and accumulated bills for the service.

To mitigate the potential of premature maintenance, Daimler Motors of Brazil has done work in the area of flexible service intervals for passenger cars and trucks. The premise is based on information impulses being delivered every 10 seconds from the vehicle system CAN controller, on twelve key operational parameters that represent the most frequently serviced elements of the vehicle. These parameters include engine, transmission, and brake pad data. The Flexible Service System can be recalibrated based on changing vehicle loads and conditions. The system can broadcast its service messages to the operator via the conventional vehicle dash for ease of use (dos Santos & Onusic, 2002).

American and European Interoperability

Another issue with diagnostics practices has been a general lack of consistency between European, Asian, and American passenger car diagnostics protocols. Since the 1990s, U.S. original equipment manufacturers have used the SAE standard J1850, the common American standard for commercial passenger car diagnostics. At the same time, European manufacturers have used CAN as their chosen protocol. For years, this discrepancy contributed to increased costs for global congruency, as well as needless over-complexity. The Ford Motor Company acquisition of Land Rover, Volvo, and Jaguar was one reason for the adoption of a single standard.

In May 2000, Ford commissioned a work team to come up with a standard that would capture and abstract all worldwide passenger car diagnostics protocols into a single readable format that could be understood regardless of which protocol was being used. This effort gave rise to the International Standards Organization (ISO) 14229-1 standard, Unified Diagnostics Services (UDS). This standard normalizes communication management, data read and write identifiers, data storage, and controller data software updates. While originally intended for the commercial passenger car market, it is worthy of note that the UDS standard was developed independent of any specific protocol. In theory, it could be used for any system that requires diagnostics data communication between systems (Miller, Thomas, & Waldeck, 2004).

Fuel Economy and Maintenance

In an age when fuel economy is one of the highest priorities, advancements in the areas of engine control and diagnostics are sought after as never before. Scientists in Belfast, Ireland, are using analysis of years of statistical data to gain a greater understanding of what generates an engine fault and how to predict when that fault is going to occur (McDowall, McCullough, Wang, Irwin, & Kruger, 2007). Current fault-detection technologies are software model-based, which isolates detected readings that fall outside prescribed norms. They are also knowledge-based, which relies on prior intuitional knowledge on conditions that create the faults. Also, they are data-based, which allows for the training of the model via neural network methodology, independent of the process involved in the fault detection. The techniques used and models developed are constantly maturing to the next level of resolution to accommodate the global need for lower emissions and higher fuel economy.

OnStar and Diagnostics

Another application that merits mention from a commercial diagnostics standpoint is General Motors' use of the OnStar Corporation's OnStar® product. Since 2005, GM has offered diagnostics notification to the customers who subscribe to OnStar for a monthly fee.

> The new "only GM" service, *OnStar Vehicle Diagnostics*, automatically performs hundreds of diagnostic checks on four key operating systems—the engine/transmission, anti-lock brake, airbag and OnStar systems—in GM vehicles. The vehicle is automatically programmed to send the results via e-mail to the owner each month. The unique email report also provides maintenance reminders based on the vehicle's current odometer reading, remaining engine oil-life and other relevant ownership information (GM's Total Value Promise to Feature OnStar's New Vehicle Diagnostics Service, 2005).

One of the main benefits of OnStar is automatic e-mail reports sent directly to subscribers offering simply documented information on the diagnostic condition of the major subsystems on the vehicle. Also, the service offers notifications to the subscriber of maintenance due, based on mileage and time. At this time, discrete engineering-level fault information is left off the reports to aid in simplicity ("GM's Total Value Promise," 2005).

The American Trucking Industry

The American Trucking Association's Technology and Maintenance Council (ATA-TMC) issues a regular recommended practices guide that outlines key areas of focus for truck maintenance. The areas include training guidelines, recommended function key placement for off-board test computers, data bus interface standards, and the software application interface to allow diagnostics fault codes to be understood by the maintainer.

Much like the Army, ATA prefers multimedia training aids that state clear-cut goals of the training module. In essence, each maintainer would know that "upon successful completion of XYZ technical training program, the technician will be able to repair and maintain XYZ product or system." According to TMC recommendations, each training module for a specific vehicle system includes:

- An overview of the system and the theory of operation;
- How to perform preventive maintenance on the system;
- How to troubleshoot the system;
- How to remove and replace components on the vehicle;
- How to remove and install a specific part;
- Parts failure analysis (ATA, 2004, pp. 503B-1).

ATA-TMC issues a function key definition and placement guideline to encourage common interface designs for developers of diagnostics information systems for use in the shop environment. The recommended practice stresses common help function key definitions that are similar to Windows functions. Also, the recommended practice focuses on basic maintenance capability, including engine, transmission, dash display, and anti-lock brake diagnosis. This encourages a level of innovation and creativity in the differentiation of product offerings, while maintaining common approaches to accomplishing the task (ATA, 2004, pp. 507-1).

American Trucking Association and Society of Automotive Engineers Protocols

The serial data bus interface standard to which ATA conforms, for use, is the same SAE J1939 and J1708 standard that is in use on the Army tactical truck fleet and construction equipment. The TMC recommendation covers the following three areas (Figure 4):

- J1939/1708 connection interface;
- Connection to hand-held diagnostics computing device;
- The vehicle-to-desktop-computer connection.

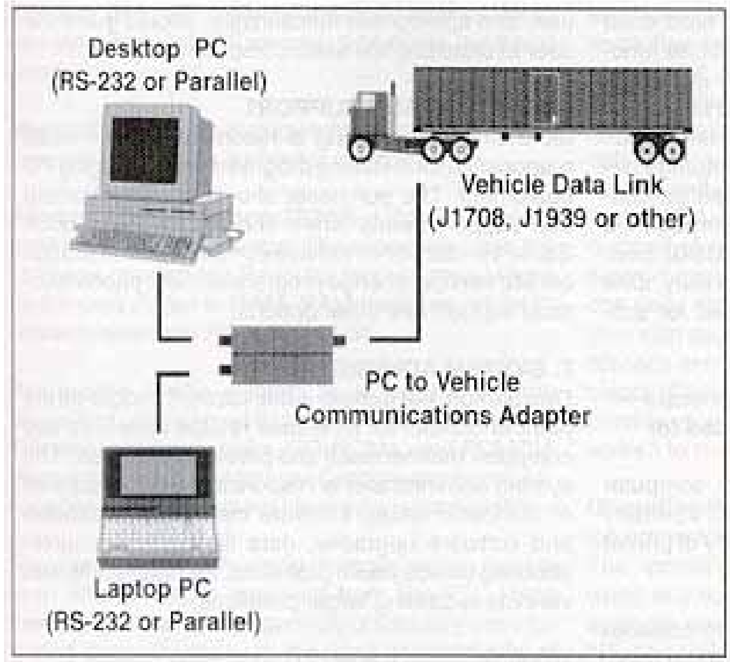

Figure 4. Diagnostics Connections (ATA, 2004)

Much like the Army, commercial long-haul trucking uses primarily off-board test computers. As can be seen from Figure 4, the most significant trucking contribution to the Army, the serial data bus, offers a highly convenient interface point to connect any type of computing device with the ability to host diagnostics software. The capability can be integrated almost as easily as an off-platform solution, giving rise to the prospect of a vehicle diagnostics computer. The maturation of computing technology suggests that price points are getting to the point where a computing device in each vehicle is not out of the question (ATA, 2004, pp. 1202A-1).

American Trucking Association Software Interface Standards

The ATA TMC mandated software interface is the RP-1210A-compliant digital link library (DLL) (Figure 5). This standard is important because it provides a software interface to enable the understanding of diagnostic fault code information, regardless of the hardware interface. It allows proprietary product differentiation, while maintaining interface consistency between hardware vendors. It enables a company like International Truck and Engine to produce a maintenance software suite that can be hosted on a third-party vehicle computing device like the Driver Tech DT-3000, while Mack Truck can seamlessly host its own completely different software suite on the same computer. It also allows applications from multiple software vendors to be hosted on one computer and communicate to several different OEM platforms as long as each platform and the computer have the same data bus interfaces (ATA, 2004, pp 1210A-1).

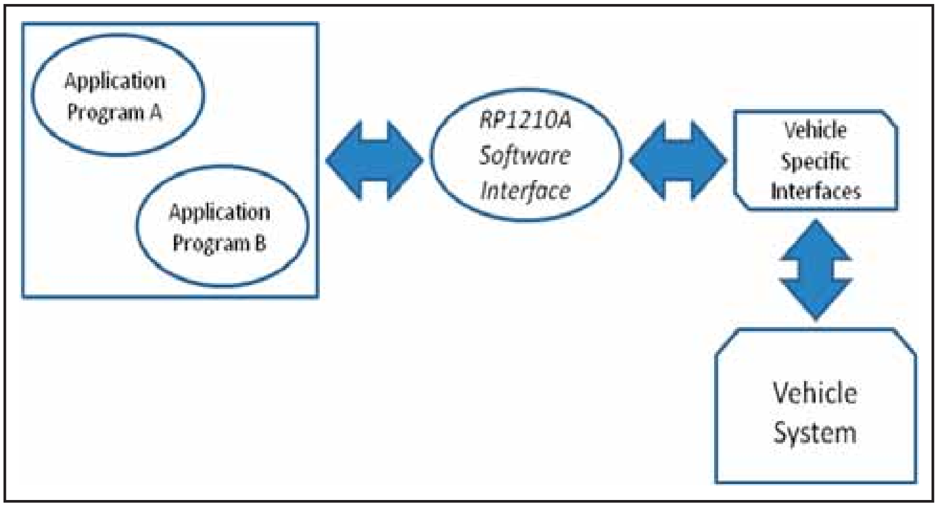

Figure 5. RP 1210A Software Interfaces (ATA, 2004)

Commercial Maintenance Management—International Truck and Engine

International Truck and Engine has a long history building truck and civil vehicles for both commercial industry and the military. During World War II, International built the Army's M-series trucks that served as troop carriers, cargo transport, and light artillery platforms. The company currently has a commercial base in excess of $9.6 billion, consisting of school buses, long-haul trucks, and civil engineering vehicles (bNet Research, 2005).

The International *AWARE*™ telematics product is International Truck and Engine's enterprise solution for streamlining maintenance processes. The approach is based on real-time monitoring and notification of service needs to reduce scheduled and unscheduled downtime. Remote access to fault data with time stamp, problem description, and components affected help to reveal conditions as they occur and potentially prevent stranded vehicles. *AWARE*™ monitors key vehicle parameters like fuel usage, battery voltage, engine hours, and accessory equipment to provide comprehensive reports for maintenance teams to improve fleet efficiency and uptime ("International: News Detail," 2006).

The product Web site <www.internationaldelivers.com/site_layout/telematics/index.asp> states that *AWARE*™ has the ability to store and retrieve a vehicle-specific bill of materials and correlate that equipment list with the fault that has just occurred, offering a convenient connection point to parts that need to be ordered to fill the impending maintenance request. This results in fewer technicians needed and fewer replacement vehicles required for filling mission quotas (International Truck Brochure, 2007).

Literature Analysis as a Research Tool

The literature review was vital to gain critical information on institutional Army maintenance procedures and the principal metrics the Army uses to measure maintenance success. Turnaround time is one of the two most important metrics that maintenance organizations use to grade maintainers and processes. The author's initial thought was that the introduction of any form of maintenance technology over and above the current off-platform test equipment would result in lowering turnaround time and increasing efficiency.

Additional investigation into Army research materials was required to best rationalize the data from the Integrated Logistics Analysis Program data stores and the information provided by International Truck and Engine. The further investigation helped provide some level of understanding of the methods and practices that the Army uses to measure success. Once those materials were understood a position could be formulated to evaluate the *AWARE*™ product's validity and potential for improving Army maintenance turnaround time.

CHAPTER 3
RESEARCH METHODOLOGY

Two research methods were used in the formulation of this report: independent data collection via access of the Army's Integrated Logistics Analysis Program (ILAP), and interviews with maintenance personnel at International Truck to gain insight into how the commercial industry uses technology to reduce maintenance turnaround time. Information from these discussions helped to establish the connection between International Truck's commercial maintenance practices and discrete elements that comprise maintenance turnaround time for the Army.

It was originally anticipated that International Truck would be able to provide quantifiable statistical data on maintenance turnaround time from their *AWARE*™-equipped vehicle systems It was determined during the research phase of this study that no quantifiable data yet exists, since the product is in the early stages of development. Anecdotal information gained from the discussions is used to formulate a position and direct further recommendations and research.

Integrated Logistics Analysis Program

The ILAP data store is a software-based utility that compiles maintenance data on each platform in the Army inventory. ILAP is accessed through the Logistics Information Warehouse, the primary logistics support data warehouse for the Army (Figure 6).

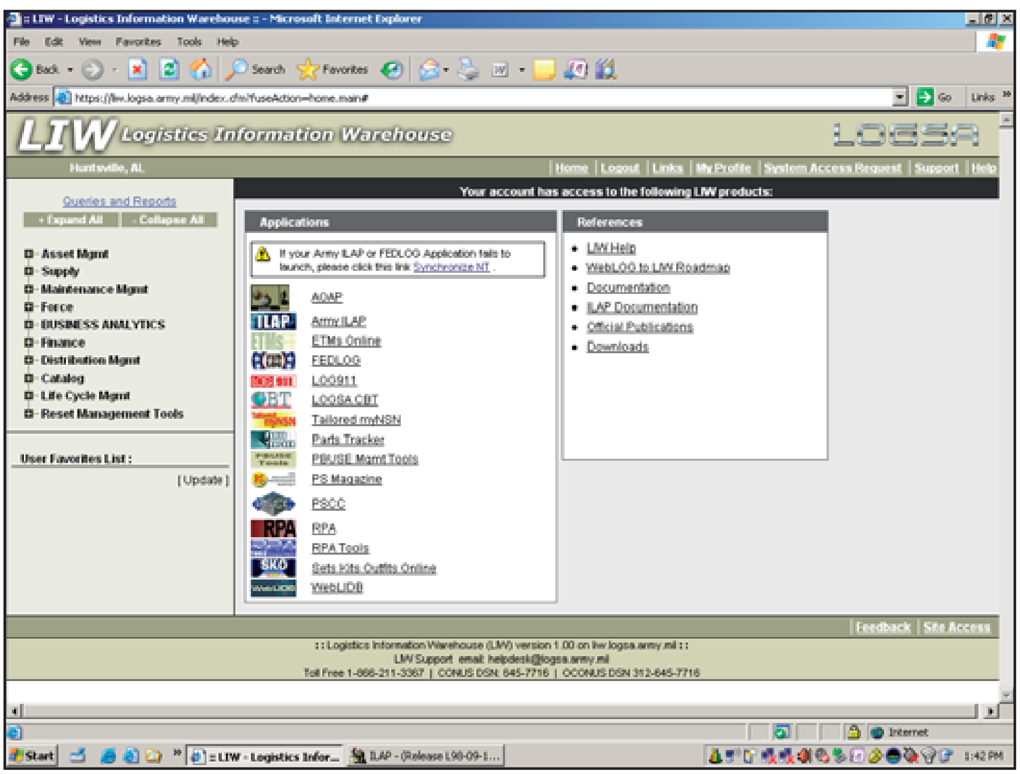

Figure 6. Logistic Information Warehouse Portal (Data Sources for ILAP Reports, 2008)

Specifically, the parameter of maintenance turnaround time is easily obtainable for vehicle systems by major subordinate command, fielded unit, and installation. For the purpose of this report, the Army system of focus is the M915 series line haul truck, the rationale for the selection being the M915's SAE-compliant diagnostics commonality ("6X6 Military Tractor," 2008) with International Truck platforms (International Truck brochure, 2007); and the areas of focus were Iraq, to provide insight into the activities of combat maintenance activities, and Fort Hood, TX, to gain converse insight on Army maintenance activities in a non-combat environment. In order to obtain information from ILAP one must enter the search parameters that correspond to the desired vehicle system and the desired time frame. Sample data can be captured for months, quarters, or years. For the purpose of this research, two quarters were targeted: April 1 to June 30, and July 1 to September 30, 2007 (Figure 7).

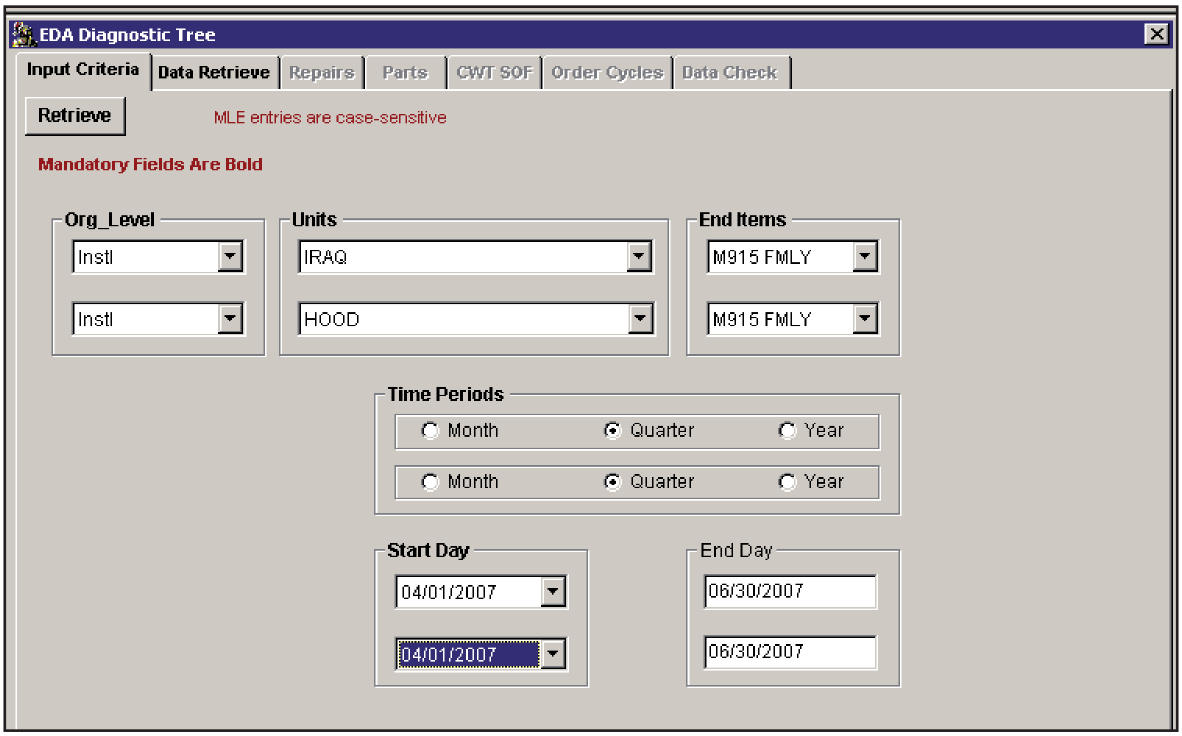

Figure 7. Input Criteria for ILAP Data Sample – April to June 2007 (Data Sources for ILAP Reports, 2008)

Entering in these search criteria produces a report in tree form that contains a significant amount of useful data on to fleet size at each local level, number of maintenance actions assumed in the quarter, and other important data pertaining to the average organizational times taken to complete maintenance actions (see Appendix 1–***FOR DOD VIEWING ONLY***).

Data parameters can be read directly from the tree. Parameters of particular interest for this study are the following, as defined in the ILAP Web portal:

- ***Fleet Size***—The number of vehicles of the searched version under the area of responsibility for that installation during the specified period of the report;

- ***Repairs***—The total number of repairs for the selected installation during the period of the report;
- ***Total Repair Days***—The average repair cycle time, in days, for the installation for the specified period of the report;
- ***Order***—The average time between when a vehicle arrives in the maintenance depot and when the required repair part is ordered;
- ***AWP***—Average organizational time to wait for an ordered part;
- ***Pt_Pick_Up***—Average time consumed for pickup or receipt of the parts required to complete the maintenance action;
- ***Fix***—The number of average actual days of "fix" time;
- ***Total Repair Days***—The total average repair time, in days, to fix problems, returning the vehicle to mission-capable readiness from a state of nonusability;
- ***Org_Level Repair Days***—The total average repair time for all maintenance activity.

This small glossary of terms is a list of data definitions included as a reference tab in each ILAP report ("Data Sources for ILAP Reports," 2008). The information collected from this ILAP report is used in this study to determine the most time-consuming elements of the repair process.

Interviews and Discussions with International Truck and Engine Corporation

The interviews and discussions with International Truck maintenance personnel provided valuable insight on how International Truck's technology approach, specifically the International *AWARE™* telematics and diagnostic product, reduces maintenance turnaround time on their vehicle systems. International *AWARE™* uses advanced software and data communications approaches to obtain real-time awareness of the readiness condition of their vehicles.

International Truck has historical knowledge and history in commercial trucking, civil engineering, and military truck development. The contention is that the company's experience in developing products for the commercial industry may provide valuable data and insight on how to best impact maintenance processes in the Army.

Questions Asked of International Truck Representatives

International Truck representatives were asked a series of open-ended questions directed at establishing the development progress of *AWARE™* and its applicability to Army maintenance. The discussions were held on two occasions, in January and February 2008, with James Thomas and Andrew Merrick of International Truck's Serviceability Group in Fort Wayne, IN. Additional supporting information was provided by e-mail in March 2008. Specifically, inquiries were made about military security requirements, vehicle fleet size, and compliance to commercial standards. Following are the questions asked.

1.	**What is the development direction of the *AWARE*™ product, and what inspires that direction?**
2.	**Where is *AWARE*™ deployed?**
3.	**What wireless communications does *AWARE*™ utilize?**
4.	**Does *AWARE*™ capture diagnostics message information? What type?**
5.	**Does *AWARE*™ perform diagnostics functions?**
6.	**Which commercial standards does *AWARE*™ subscribe to?**
7.	**Does *AWARE*™ have any automated functions?**
8.	**Does International have any historical data on maintenance turnaround time? If so, how is it used?**

Table 2: Questions to International Truck

In addition, International Truck was asked to provide any supporting evidence of impact that the *AWARE*™ product has on any of the systems equipped with the technology. It was suggested that include positive or negative user testimonials.

CHAPTER 4
RESULTS PRESENTED

The presentation of the research results will be divided into two components: the Integrated Logistics Analysis Program data; and the information from International Truck. The ILAP data has a high degree of statistical value, while the information from International is very anecdotal.

Accumulation of data to describe maintenance activity in Iraq and Fort Hood, TX was a straightforward process. Querying the ILAP data warehouse yielded concise, easy-to-understand data that readily explain maintenance activity and factors affecting turnaround time. The Army personnel generating the data are the Army mechanics working on tactical trucks in Iraq and Fort Hood. To reiterate the parameters stated in the Research Methodology section, the focus of the data collection was the M915 series truck and activity from April to September 2007.

Determining the number of maintainers working on a specific system is not an easy task. Army mechanics work on multiple vehicle systems and have many other duties besides performing maintenance. Also, the identity of personnel and unit information for maintenance activities in Iraq are operationally sensitive and not common knowledge. Typically, however, one mechanic in a maintenance organization might average 30 or more maintenance actions per 90-day period. In April to September 2007, there were over 350 M915 truck work orders completed in Iraq. That means potentially 12 or more mechanics would have been doing repair work on those systems during that time.

The gathering of diagnostic data from International Truck was also not straightforward. As stated earlier, the *AWARE*™ product is still in development. While the desired approach for International Truck is to develop a solution that can help the Army improve efficiency in maintenance, at the time of this writing, the company has no quantifiable turnaround time data, to compare with the ILAP results. International Truck anticipates being able to develop a solution that will yield measurable data sometime in 2009 (see International Truck and Engine Data and Summary and Further Recommendations sections).

ILAP Data

Examples of sample reports retrieved from the ILAP data store reveal some interesting information on the elements that affect maintenance turnaround time. In Iraq in 2007, the Army had in service over 700 M-915 series line haul trucks. The M915 series vehicle is produced and sold to the Army by Freightliner Corporation, and has much commonality with the vehicles that International Truck sells to its commercial customers, hence its significance in this study.

ILAP, as stated earlier, provides tools to analyze equipment downtime and provide granular detail on the elements contributing to the time it takes to repair systems in the field. The utility tells us that during April to June 2007, there were over 350 repairs performed on M915 series vehicles (see Appendix 1—***FOR DOD VIEWING ONLY***). ILAP also tells us that the total average repair time to bring systems from a state of non-usability back to mission-capable readiness was an estimated 19.5 days. Additionally, the total average repair time for all activity, including non-mission capability-related repairs was an estimated 21 days.

Table 3–2
Maintenance priority designator and TAT standards

Maintenance priority designator	TAT standard
01–03	5 days
04–08	8 days
09–15	30 days[1]

Notes:
[1] Customer organizations may specify a required delivery date that is longer than 30 days when mission schedules permit.

Force Activity Designators
I: In Combat
II: Positioned For Combat
III: Positioned to Deploy
IV: Other Active and Reserve
V: All Other

Urgency of Need Indicators
A: Unable to Perform Mission
B: Impaired Operational Capability
C: Routine Issue

Figure 8. Priority Designators and TAT Standards
(Army Materiel Maintenance Policy, 2007)

According to the Army Materiel Maintenance Policy, all mission capability-related repairs for combat assets should be completed in 5 days or less (Figure 8). Given this fact, maintenance turnaround time for the M915 series vehicles for the months of April to June 2007 did not meet minimum standards as dictated by Army regulations.

At Fort Hood, maintenance times for April to June 2007 were even less optimal. Total average repair times for mission capability related repairs were an estimated 28 days. Repair time averages for all assets, including those not related to mission capability problems, were an estimated 35 days. Given the differences in M915 fleet sizes between Fort Hood and Iraq, additional analysis is merited to determine where bottlenecks could be occurring.

For the Iraq M915s, average time to order parts after the vehicle has reached a state of not-mission-capable is less than 2 days, compared to just over 2 days at Fort Hood. Average wait time to acquire ordered parts was nearly 2 weeks in Iraq as opposed to just over 1 week at Fort Hood. Also, the time to transfer and deliver the ordered part prior to the service work's being carried out is virtually the same—just about 3 days—in Iraq and Fort Hood. Where the significant difference occurs is in the time to complete the repair. Average actual work time in Iraq on the M915 fleet is about 4 days, compared to 15 days in Fort Hood. That is an interesting statistic and may suggest more focus is paid to organizational maintenance tasks in the war zone than at vehicle deployment facilities in the United States. It may also suggest that repair resources are being dedicated to the combat area of responsibility as a priority over any areas not in a war zone. The data do suggest that elements that are, by and large, out of the maintainer's control, such as lead time to acquire an ordered part, are causing some of the most significant regular impacts on turnaround time.

A gathering of data for the same organizations, for the months of June to September 2007 provides some additional interesting insights (see Appendix Appendix 1—***FOR DOD VIEWING ONLY***). The numbers stayed somewhat in line with the previous quarter in Iraq. The average time from the vehicle's arrival in the maintenance depot to ordering of parts was just under 2 days, with an average wait time for parts of 11 days. Part pickup time was noticeably lower, at less than 1 day. The time to complete the work, also known as "fix" time was almost twice as much, at an estimated 8 days. Also, the average organizational repair time was 3 weeks, very close to the previous quarter.

More interesting were the statistics at Fort Hood. The average time to complete the repair work was nearly 2 months, with an average time of zero days to part order after the vehicle came in for repair, indicating that no time was wasted prior to ordering parts. That the average time to wait for parts was down significantly at 3 days, supports the theory. With 1 day to pick up the repair part (significantly lower than the previous quarter), the data show possible effort to lower the cycle times.

Of significant interest is the average repair work time of nearly 2 months. It may suggest that the maintenance organization was busy with other tasks related to soldier support—perhaps preparation and positioning of M915 vehicles to deploy. Wartime activities specific to that timeframe may have necessitated soldiers preparing to ship vehicles that were ready for service and placing a lower priority on maintenance actions on non-mission-critical systems. Efforts to contact maintainers at Fort Hood to gain some level of insight on the data have been unsuccessful up to the point of this writing.

International Truck and Engine Data

Among the information gained from the discussions with International Truck is that they intend to take development of the *AWARE™* product in the same direction proposed by this study (see *Findings and Further Recommendations* section). International Truck's goal is to utilize vehicle diagnostics sensors and communications technology to automate data collection and diagnostic actions. They also intend to incorporate the interchange between the diagnostic data and their own version of the interactive electronic technical manual to speed up the repair process. International Truck's experience building trucks for the military suggests that they could successfully produce a product that satisfies the Army's needs.

Answers to the questions asked of International Truck (see *Questions Asked to International Truck* section) describe a philosophy of developing a solution that provides an autonomous function to improve maintenance efficiency. The goal is to impact their business processes and potentially to benefit customers like the Army.

Following are answers to the questions asked of James Thomas and Andrew Merrick of International Truck's Serviceability Group in Fort Wayne, IN.

What is the development direction of the *AWARE*™ product, and what inspires that direction?

Vehicle fleet managers have been looking for ways to gain additional real-time awareness of vehicle health for years. On-road breakdowns and catastrophic events are recurring problems that impact transportation fleet success. Having the ability to monitor vehicle readiness and be able to react to that information is vital to consistent business. The availability of the Internet also offers a convenient way to access that information in real time. That is what inspired the development of the *AWARE*™ system.

Technologies like wireless communications and vehicle electronics architecture help to get diagnostics data to the fleet managers from the truck while it's on the road. This helps [them] to plan unscheduled maintenance and manage parts buys in more of an as-needed fashion. Our experience with the Army tells us that they would like the same capabilities.

Where is *AWARE*™ deployed?

Currently, as our test base, we have 1,800 vehicles equipped and running mostly in the Midwest. We can trace each vehicle through a Web-based software application that reports its location on a map display. We have plans to deploy the system throughout the continental United States and Canada in 2009.

What type of wireless communications does *AWARE*™ utilize?

The system communicates through a cellular link on the Verizon network. The system uses CDMA (Code Division Multiple Access) encryption. This type of encryption spreads the signal over multiple channels within the whole signal bandwidth, with each channel using a distinct digital code. This increases efficiency, performance, and security ("CDMA IS-95," 2007).

Does *AWARE*™ capture diagnostics message information? What type?

Yes. From the 1,800 International trucks, the system is collecting J1708, J1939, CAN, and proprietary Navistar diagnostic data. These messages are in the form of trouble codes that can be cross-referenced with fault definitions to determine what issue the vehicle system might be experiencing. Currently, we are collecting raw fault code data from the 1,800 platforms and saving it for analysis at our Fort Wayne facility.

Does *AWARE*™ perform diagnostics functions?

That capability is currently in development. We're in the process of hosting diagnostics manuals on the Internet with the goal of tying the raw message data directly to the diagnostic manual for up-to-the-minute diagnosis of vehicles while they are being driven. This is a function that we hope to have completed in the near term future.

Which commercial standards does *AWARE*™ subscribe to?

We are compliant with Society of Automotive Engineers J1708, J1939, CAN, and proprietary Navistar standards. J1708 and J1939 are also in standard use on Army truck platforms, which creates a common architecture base.

Does *AWARE™* have any automated functions?
Currently, the only automated function that *AWARE™* performs is real-time diagnostic data passage from the 1,800 vehicles to the facility in Fort Wayne. We are also able to track the vehicles through our Web portal, and display locations on an on-screen map. The goal in the future is to automate our parts requisition system and design in service scheduling and notification to our drivers.

Does International have any historical data on maintenance turnaround time? If so, how is it used?
Currently, we are cross-referencing fault code data from our platforms with historical warranty repair data to determine if there are any trends that connect the two. What we've been finding is the repair is usually bigger than what the fault code is telling us. We're not certain if this fact is due to irregular record keeping or if the diagnostics fault information does not adequately describe the problem. Either way, International is working towards solving this issue because it is critical to using fault data to autonomously trigger a part requisition.

Separate e-mails were sent to International Truck asking if there is any other evidence to suggest that the *AWARE™* product has positive impact on maintenance turnaround time. Following is the e-mail response from Andrew Merrick, dated March 24, 2008:

> The best example of use of telematics to impact maintenance of the vehicle occurred on one of our engineering test fleet vehicles. These vehicles were all built from the factory with the *AWARE™* system, and the data were watched nightly by the controlling engineer—even as the trucks were delivered to customers all over the U.S. On one brand new vehicle, the overseeing engineer noticed an anomaly in one of the fuel injector's fuel-consumed number. As this vehicle was just out of the factory and heading down the road to its customer delivery, he theorized that the fuel line to that particular fuel injector was not fully torqued down at the factory, and he made a call to the driver of the vehicle to take a look under the hood. This type of failure would have provided little noticeable effect to the driver but would have led to a greatly decreased fuel economy, so it was only through telematics that such a failure could have been detected early. The driver did check the particular fuel injector, tightened the fuel supply line, and was back on the road, getting optimal fuel economy in a matter of minutes.

Judging from the answers above, it's evident that International Truck is developing a telematics-enabled diagnostics and maintenance solution that has potential for positive impact on maintenance turnaround time. The company's history of developing vehicles for the American military and its expertise in military standard diagnostics architectures should support migration of its commercial products into the Army's maintenance processes.

An area that needs significant development is a communications schema to support Army mission requirements. Currently, *AWARE™* uses Verizon commercial cellular technology as its communication layer. In locations such as Iraq and Afghanistan, this infrastructure does not exist. A serviceable communications pipeline would have to be established, with the requisite security implementations in place, in order to successfully deploy a product like *AWARE™* in current Army war zones. The Army utilizes radio-based communications infrastructures that feature the necessary security (Fort MonmouthTeam C4ISR, 2008). If the vehicle data could be packaged to fit into one of those infrastructures without interfering with other critical communications, this would enhance prospects for integration.

Deployment, however, would take some time. Any vehicle electronics would need to be designed to handle the rigors of the military environment (U.S. Army Electronics Proving Ground, 2007). Similarly to how International deployed its 1,800-vehicle test fleet, the Army would have to phase an implementation, which would include military testing of hardware and software. Perhaps the best approach would be in small numbers starting at installation level. Such an approach would allow proof of concept and maturation at the several-hundred-vehicle level prior to wider expansion of the technology.

Among the positives of that approach is the use of the Internet as the main user interface to manage the maintenance information. Similar to the Army Logistics Support Activity (LOGSA) management of ILAP data, maintenance data collected via the *AWARE*™ product could be ultimately stored and managed in the LOGSA Information Warehouse. This feature is critical for establishing maintenance-trend analysis and work-order history. The approach of remote diagnosis using the Internet as the means to survey the state of deployed vehicle systems is another significant potential benefit to the Army.

CHAPTER 5
SUMMARY AND FURTHER RECOMMENDATIONS

DISCLAIMER: The following conclusions and recommendations are, in no way, an endorsement or demonstration of bias for any specific commercial technology supplier, technology solution, or business approach. The author fully supports and follows Army regulations for full and open competition.

The information gathered from the Integrated Logistics Analysis Program (ILAP) supports the idea that there is room for improvement in maintenance processes to improve turnaround time. The ILAP data tell that, in the months between April and September 2007, there were relatively long wait times for repair parts in Iraq. Those wait times added significantly to total turnaround time and caused Army maintainers to exceed regulation metrics for turnaround time in a combat zone (Army Materiel Maintenance Policy, 2007).

Actual repair times were, on average, significantly lower than wait time for parts. However, at different times during the sample period, repair time by itself exceeded the recommended metrics for acceptable maintenance turnaround time. This is likely attributable to maintainer workload and the fact that soldiers move to other tasks when waiting for repair parts. Also, since there is significant manual recording of work order data, it should not be ignored that some of this data could be attributable to faulty record keeping.

International Truck and Engine Corporation Findings

The Army findings certainly make a case for insertion of commercial technology that can improve maintenance turnaround time. International Truck and Engine Corporation's *AWARE*™ product is in development with the intention of creating a system for International Truck's fleet managers to increase diagnostic situational awareness and improve their maintenance processes. Their philosophy includes developing the product to help potential customers like the Army impact their truck fleet in the same way. The *AWARE*™ approach addresses real-life problems for maintaining readiness of vehicle systems under normal conditions and in the event of catastrophic failures. The approach also supports the philosophy that fleet managers in commercial industry and the Army alike have the same sorts of maintenance issues that impact short- and long-term success.

The use of commercial electronics and wireless communications technologies is an area that has been under investigation in many unconnected initiatives by the Army for several years. The approach that *AWARE*™ uses to integrate those technologies offers a reasonable and convenient way for the Army to adapt the technologies in one single solution.

As stated earlier, issues such as secure communications and militarization of vehicle electronics would need to be addressed for the *AWARE*™ product to be effective and successful. Following is a possible path forward that addresses security and militarization issues to create a transferable solution for Army truck platforms.

Path Forward—Additional Research

International Truck is currently collecting fault code data from 1,800 vehicle systems equipped with the *AWARE*™ technology. This path forward would start with a teaming arrangement with International Truck or any other vendor with a similar pilot program, to gain access to diagnostic data to analyze which fault conditions are occurring and how often. A detailed connection would be made with the fault data and repair histories to develop trend analysis. The trend analysis would help Army engineers make the connection between fault and symptom codes and impending failures. The information would also assist in supply-on-demand parts-ordering and preemptive diagnosis of problems.

As follow-on to this data analysis phase, a similar test vehicle pilot program could be instituted on an Army family of vehicles while on deployment. This platform family could well be the more than 700 M915 vehicles in Iraq, or any other family equipped with an SAE-compliant diagnostic data bus, to enable easy data collection. This Army test deployment is very important.

While Army trucks in places like Iraq perform transport missions similar to those of commercial over-the-road trucking, much of the transport is cross country as well as on paved roads. Also, the life-and-death urgency of the Army mission often causes operators to push vehicle systems harder than their commercial counterparts. It is imperative to develop trend analysis based on those differing conditions.

Another important element of this deployment will be to make certain that all electronic devices used in the vehicle systems are of military ruggedness. That will require a separate battery of Army tests (see Appendix Appendix 1—***FOR DOD VIEWING ONLY***).

The requirement for secure communications could be achieved by using some of the bandwidth of the tactical secure radios already employed by the Army. If that proves insufficient for the data passage needs, satellite communications could be used as an alternative, taking into account that reliability can be adversely impacted by weather conditions and other environmental concerns (“Fort Monmouth—Team C4ISR,” 2008).

Another possible alternative would be to combine radio’s security features and short-range reliability with satellite’s long-range capability. Both radio and satellite communications are in widespread use in the military and can be used as surrogates for one another, depending on the vehicle’s proximity to the maintenance depot.

It should also be mentioned that it could be possible to develop and apply a security layer to conventional cellular or long-range wireless broadband (WiMax) communications (“WiMax Forum,” 2008). The effort would also require developing and installing an infrastructure to support it in the areas where the Army deploys. This is an initiative that would require significant resources and time, and should certainly be considered separately from this research.

To establish the network enterprise, Internet connectivity would need to be established, if none exists, at the maintenance organizations in the deployment zone. As part of the test deployment, local data storage facilities would be created to collect the vehicle test fault data for subsequent download to LOGSA's Information Warehouse. Also, connectivity to Standard Army Maintenance System (SAMS) and Unit Level Logistics System (ULLS) would be established to catalog work order data and enable parts requisitioning. As part of the test enterprise system, up-to-date versions of vehicle Interactive Electronic Technical Manuals would be hosted on maintenance organization computers to help perform preemptive diagnosis on incoming fault code data from vehicles in the field. Based on data collected from the diagnosis, a work order could then be started in SAMS and timely parts ordering could be instituted in ULLS, all before the vehicle reaches the maintenance bay.

The goal of this test deployment would be to shorten the individual elements of the repair cycle to reduce maintenance turnaround time. Data would be analyzed from the work orders to substantiate any improvements in turnaround time. In order to collect enough data to justify the adoption of the *AWARE*™ technology, the test deployment would need to be active for as long as possible. A year would likely provide enough information to justify technology transition.

Expected outcomes of this effort include an expanded justification to utilize commercial maintenance technology—such as International Truck's *AWARE*™ product—to shorten repair cycle times. Transitioning technology into the Army inventory can be a lengthy process. Any change would certainly be an adaptive one, particularly on the part of Army maintainers and leadership. The focus on commercially based vehicle systems such as the M915 series truck allows for a potentially less disruptive effort. While this study and follow-on research effort represents a fundamental adjustment in the way the Army conducts maintenance business, it professes to maintain the long-standing critical strategy, identity and core values of the Army.

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APPENDIX – FOR DOD VIEWING ONLY

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Defense Acquisition University Midwest Region
ATTN: Dr. Roland Kankey
3100 Research Blvd, Pod 3, 3rd Floor
Kettering, Ohio 45420